AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

PRELIMINARY HAZARD ANALYSIS
FOR THE
ISOTOPE BRAYTON FLIGHT SYSTEM

Prepared in Support of ERDA Contract E(04-3)-1123

by

AiResearch Manufacturing Company of Arizona

October 31, 1975

75-311629

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Approved by: J. E. McCormick

J.E. McCormick, BIPS
Program Manager

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This Preliminary Hazard Analysis (PHA) of the BIPS-FS is a tabular summary of hazards and undesired events which may lead to system damage or failure or personnel injury or death. The PHA uses the following symbols to identify the "Program Phase" of interest:

- GND - Ground Handling/Transportation
- PAD - Prelaunch and Countdown
- LIO - Launch and Insertion Into Orbit
- OPO - Operational Use (any time BIPS is operating)
- IMP - De-orbiting/Re-entry/Impact

The following symbols have been used under the heading "Hazard Category" to denote the potential result of the identified hazard/undesired event. (The first column denotes the estimated severity before "Corrective Action/Minimizing Provisions" have been identified; the second column indicates the estimated potential for eliminating or minimizing the effects.)

- I - Negligible - will not result in personnel injury or system damage
- II - Marginal - can be counteracted or controlled without injury to personnel or major system damage
- III - Critical - will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival
- IV - Catastrophic - will cause death or severe injury to personnel or system loss

The PHA tabulates recognized hazards/undesired events affecting the BIPS-FS. Comments and suggested changes and additions should be forwarded to AiResearch Manufacturing Company of Arizona, Attn: L. G. Miller, P.O. Box 5217, Phoenix, Arizona 85010.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/BRU							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
1	Acceleration	LIO	Launch vehicle acceleration	Possible damage to foil bearings if BRU is required to operate during launch	IV	I	Design the BRU bearings with capacity sufficient to support launch load of rotating shaft. (Performance degraded through bearing losses.) Investigate g-loads to be sustained in changing orbits to determine ability of BRU to operate if required. Increase load capability of journal bearings (with small sacrifice in efficiency) if required to align BRU in horizontal orientation.
2	Impact and Shock	GND	Dropping of BRU	Possible damage to rotor bearings for impacts >50 g	II	I	Use extreme care in handling during all operations. Design special handling and shipping containers; design handling fixture for use when

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/BRU
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
2	Impact and Shock (Contd)						out of shipping container.
3	Electrical System Failure	OPO	Inadequate or deteriorated insulation on stator wind- ings; short circuits; open circuits	Alternator failure or decreased out- put	IV	I	Perform high pot. tests prior to assem- bly. Use "burn in" techniques to elim- inate early failures. Study candidate in- sulation materials for alternator wind- ings. Adopt strict quality control procedures.
4		OPO	Excessive electrical load	Complete sys- tem shutdown if not cor- rected by load shedding.	IV	I	Design of control system can preclude.
5	Structural Damage or Failure	OPO	Loss of ten- sion of tie bolt	Loss of axial lockup force, wheel rubs, unbalance, and possible bear- ing overload and failure.	IV	I	Proper design and correct assembly pro- cedure will preclude this type of failure.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/BRU
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
6		OPO	Fracture of tie bolt	Catastrophic rotor failure	IV	I	Design will provide adequate margin of safety.
7		OPO	Rotor seizure caused by bearing failure or joint separation	Complete loss of output	IV	I	Foil bearings are inherently reliable; QA will assure correct assembly of bearings and rotating group.
8		OPO	Impeller hub burst as result of overspeed	Failure of Mini-BRU	IV	I	The compressor impeller has been designed and will be tested so as to assure that minimum burst speed has factor of safety of 4.0 over normal maximum operating conditions.
9		OPO	Turbine wheel hub burst as result of overspeed, overtemperature	Failure of Mini-BRU	IV	I	The turbine wheel has been designed and will be tested so as to assure that minimum burst speed has factor of safety of 3.5 over normal maximum operating conditions.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/BRU
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
10	Structural Damage or Failure	OPO	Alternator rotor bi- metallic joint failure	Failure of Mini-BRU	IV	I	Rotor has been de- signed and will be spin tested to assure that minimum burst speed is twice the design stress.
11		OPO	Turbine blade fatigue due to blade mo- tion at higher stress levels	High vibra- tion, high shaft excur- sion, loss of performance, failure of bearings, failure of BRU	IV	I	Design is very con- servative; stresses are extremely low.
12		OPO	Crack, rup- ture, or puncture of plenum	Loss of work- ing fluid, failure of BRU	IV	?	Adequacy of plenum design is dependent upon authentication of C-103 creep rup- ture data.
13		OPO	Turbine blade creep	Unbalance bearing fail- ure; blade rubbing on shroud	IV	I	Design is very con- servative; stresses are extremely low.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/BRU							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
14	Heat and tempera- ture	OPO	Fracture of foil thrust bearing	Bearing seizure	IV	I	Design, quality con- trol, and proper assembly procedures will assure relia- bility of thrust bearing.
15		OPO	Turbine Blade erosion due to evaporation of metal	Very gradual weakening and loss in per- formance	II- IV	?	Analysis and testing required to deter- mine if evaporation is of consequence in "pure" He-Xe atmos- phere. GDS should give conclusive evidence.
16		OPO	Overheating of alternator stator (Limited to 450°F)	Damage to windings in- sulation	II- IV	I	Stator is conduction cooled (assisted by 2% bleed for turbine bearing cooling)
17		OPO	Overheating of journal bear- ings (turbine journal bear- ings limited to 500°F)	Failure of coating on bearings	II	I	Coating needed only for startup.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/BRU	
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/MINIMIZING PROVISIONS	
18	Moisture	GND	Moisture introduced into system in any manner	Ferrous metals in alternator stator and rotor could rust.	II-IV	I	Cleaning, storage, and assembly procedure will preclude.	
19	Leakage	ANY	Defective fit of case joints, electrical terminal feed-throughs	Leakage of working fluid.	II-IV	I	Quality assurance, vendor control should preclude; leakage test will detect.	
20	Contamination	OPO	Off-gassing of alternator organic material; oxides, nitrides, hydrocarbons, metal oxides, water vapor, from MBR, ducting, alternator, radiator, etc. Residual contaminants in W/F gases.	Contamination may severely embrittle C-103 structure.	IV	I	Long term creep tests required to determine magnitude of C-103 strength degradation. Off-gassing tests of alternator stator required. High quality Xe/He required as working fluid. Introduce getters in loop to absorb contaminants.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/HSA							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
21	Acceleration	L10	Launch vehicle acceleration (dynamic loading)	Fracture or cracking of HSHX flow channel vanes resulting in cross flow of working fluid.	II	I	Qualification tests are expected to confirm integrity of design.
				HSHX diffusion bonds may open resulting in degraded heating of working fluid and imbalance in system.	?	?	Criticality yet to be determined.
				Fracture of one HSHX mounting support.	II	I	Other five supports will adequately support the HSHX. Qual. tests are expected to confirm integrity of design.
				Fracture of one spoke of one end enclosure.	II	I	Other five spokes will adequately support the heat source.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/HSA							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
21	continued...	OPO	Sources inside working fluid loop: Residual contaminants in W/F gases; Oxides, Nitrides, hydro carbons, water vapor from MBR, ducting, alternator, radiator, etc. Sources outside W/F loop: Carbon, CO/CO ₂ from EHS/IHS; Oxygen, Nitrogen, H ₂ O, Hydrogen from environment and insulation/structures.	Cracking of Be external support housing.	II-IV	I	Design should preclude. (No effect on system once orbit is reached.)
22	Contamination			Embrittlement of C-103 HSHX may result in leakage or catastrophic failure.	II-IV	?	Long term creep tests required to determine magnitude of C-103 strength degradation. Develop PT3008 alloy heat source can or silicide-coat C-103 in heat source.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/HSA							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
23	Heat and Temperature	OPO	Excessive thermal stress	Fracture or cracking of HSHX flow channel vanes resulting in cross flow of working fluid.	II	I	Qualification tests are expected to con- firm integrity of design.
				HSHX diffusion bonds may open resulting in degraded heat- ing of working fluid and im- balance in system.	?	?	Criticality yet to be determined.
				Cracking of Be external support hous- ing. Loss of pre- load in pre- load fitting of HS support assembly due to creep in- duced by over- temperature (cont'd)	II- IV	I	Design should pre- clude. (No effect on system once orbit is reached.) Structural test will verify design margins.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/HSA							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/MINIMIZING PROVISIONS
23	continued..			of preload fitting. This in turn could result in movement of heat source. Possible damage to HS or HSHX causing crack or chipping of HS reentry aeroshell, or rupture of HSHX C-103 wall and leakage of W/F.			
24	Structural Damage or Failure	ANY	Defective welds	Leakage at header weldments of HSHX or inlet-outlet elbows. Fluid loss could range from negligible to catastrophic.	I - IV	I	Welds will be radiographically inspected; unit will be leak-checked. Weld process will be checked with destructive test specimens.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/HSA							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/MINIMIZING PROVISIONS
25	Vibration	LIO	Material flaw coupled with launch vibration or shock. Vibration during boost.	Failure resulting in loss of HS end supports & preload. Possible failure of one HS mounting bracket of the HS support assembly.	II	I	Vibration tests are expected to prove integrity of supports. Other five brackets would adequately support the HS. Structural tests are expected to verify design margin.
26	Structural damage or failure	PAD	Activation of ECS due to loss of ACS (premature venting of Helium)	Melt down of multi-foils comprising HSA insulation.	IV	I	Gas venting system must and can be designed with high reliability.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/MBR							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/MINIMIZING PROVISIONS
27	Acceleration	LIO	Launch vehicle acceleration (dynamic loading)	Possible rupture of pan assemblies at duct interfaces. Possible rupture or deformation of mount assemblies resulting in failure of ducting at duct/pan assembly interface.	IV	I	Proper design of mounting structure will assure that structure will resist high g-loads and will not transmit excessive loads to duct/fan interfaces. Mount assemblies should be subjected to 100% radiographic and ultrasonic inspection.
28	Structural damage or failure	OPO	Extensive exposure to overpressure and/or overtemperature	Possible rupture due to creep or yielding of fins, tube plates, header bars, splitters, side plates, or pan assemblies, resulting in per- (cont'd)	II-IV	I	Proper design of control system should preclude off-limit operating conditions.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/MBR						
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/ MINIMIZING PROVISIONS
28	continued..			formance degradation, or (in event of side plate or pan assembly rupture) complete loss of working fluid.		
29	Structural Damage or failure	GPO	Cumulative damage as result of thermal stresses of start-up, shut-down transients (Low cycle fatigue)	Rupture of fins tube plates, header bars, side plates, seal plates, or pan assemblies resulting in performance degradation or (in event of side plate or pan assembly rupture) complete loss of working fluid.	II-IV	I Unit designed to withstand 1000 start-up cycles (400 seconds to reach steady-state operating conditions. Steeper start-up transient will result in decreased cyclic life. Gold-base braze alloy is ductile and will resist low cycle fatigue.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/MBR							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
30		OPO	Incomplete brazing of fins to tube plate and/or excessive braze alloy penetration of fins.	Rupture due to creep or yielding of the fin-to-tube plate braze joint, resulting in performance degradation.	II	I	Gold-base alloy specified to obtain optimum braze alloy wetting and flow with minimum alloying and penetration. Proof pressure acceptance test will detect gross braze voids. Inspection procedures must be established to assure adequate braze alloy coverage.
31	Structural Damage or failure	OPO	Mechanical damage incurred during fabrication of tube plates results in excessively thinned parent material in localized areas. Void then occurs during brazing operations.	Pin hole leaks develop, allowing bypass flow from high to low pressure. Performance degraded.	II	I	Inspection procedures must preclude the installation of defective plates. Special handling and storage procedures should be established to prevent damage.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION IBFS/MBR							
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
32	Structural Dam- age or failure	OPO	Incomplete brazing of the header bars to the tube plates results in brazing voids.	Rupture of the header bar-to-tube plate braze joint, result- ing in loss of structural integrity but loss of work- ing fluid is prevented by seal plate.	II	I	Seal plate will act as backup structure. Gold base braze alloy has been specified to obtain optimum alloy wetting and flow with minimum alloying and pene- tration.
33		OPO	Undetected brazing voids in splitter-to- core matrix brazing joints or cumulative damage as a re- sult of thermal stresses in- duced by start- up and shut- down transients.	Rupture of the splitter-to- core matrix brazing joint resulting in bypass flow from high to low pressure. Performance degraded.	II- IV	I	Inspection procedures must assure adequate brazing alloy coverage. Resistance to low cycle fatigue is to be demonstrated by thermal cycle testing.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/MBR
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
34		OPO	Undetected braze voids in the side flange- to-seal plate braze joint.	Rupture of the side flange-to- seal plate joint, result- ing in loss of working fluid.	IV	I	Inspection procedures must assure adequate braze joint coverage. Development tests must verify that manufacturing tech- niques result in con- sistently perfect braze joints.
35		OPO	Improper instal- lation of MBR causes binding and plastic de- formation of mount assem- blies during thermal growth.	Rupture of mount assem- blies resulting from low cycle fatigue. Pos- sible rupture of attached ducting results in loss of working fluid.	II- IV	I	MBR installation procedure must assure correct alignment of MBR. Tests should assure that mounts slide freely during thermal growth and that no galling or welding occurs be- cause of exposure to space vacuum.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION		IBFS/RADIATOR					
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
36	Penetration	OPO	Micrometeoroid impact	Loss of work- ing fluid	II- IV	?	Design to NASA specification.
37	Nuclear attack	OPO	Detonation of offensive	Dependent upon yield, proxim- ity, and other factors. Could result in loss of radiator emissivity coating, af- fecting BIPs power output.	II- IV	?	Potential kill mechanisms must be evaluated.
38	Structural damage or failure.	OPO	Fatigue due to vibration; weld, braze failures.	Loss of work- ing fluid.	II- IV	I	Proper design and quality assurance procedures should preclude.
39	Shock or impact	GND	Dropping; collision.	Damage to welds and brazes; degraded per- formance could easily be catastrophic (loss of work- ing fluid; severe weaken- ing of struc- tural integrity).	II- IV	I	Handle with extreme care; design special handling fixture.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/LOOP INTEGRITY
NO.	HAZARD/UNDESIREDEVENT	PROG.PHASE	CAUSE	EFFECT	HAZARDCATEGORY		CORRECTIVE ACTION/MINIMIZING PROVISIONS
40	Contamination	OPO	Transfer of metallic elements by vaporization at high temp/vacuum conditions.	Embrittlement of refractory metals. Loss of loop integrity.	IV	?	Measure and assess the effects of evaporative mass transfer. (Embrittlement during orbital phase may not be of consequence since inertial and vibration loads occur only during launch.)
41	Contamination	OPO	CO gas from heat source can react with C103 HSHX to form $CbC + Cb_2O_5$.	Modest amounts result in C-103 alloy embrittlement in HSHX; extensive contamination can result in complete loss of HSHX integrity.	IV	?	Long term creep tests required to determine magnitude of C-103 strength degradation.
42	Contamination	OPO	Mass transport of metallic vapors from HSHX insulation to Cb alloy components.	Alter properties of refractory metal; induce creep failures.	IV	?	To be checked by experiment; may require overlay of C-103 or Mo foil.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION				IBFS/LOOP INTEGRITY			
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
43	Contamination	OPO	Outgassing of insulation materials on alternator windings.	Embrittlement and possible loss of loop integrity.	IV	?	Study candidate alternator insulation materials; limit outgassing over 7 year mission.
44	Leakage	Any	Failure of ducting joints and/or bellows.	Leakage or loss of working fluid.	II-IV	I	Double containment weld joints should be considered where feasible. Close QA control in necessary to assure quality of welds and ducts. Correct design of bellows to compensate for centerline misalignment due to thermal expansion and lateral deflection will be an absolute necessity, as is the development and demonstration of highly reliable bimetallic

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/LOOP INTEGRITY	
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS	
44	continued...						joints (C-103 to HAST-X; HAST-X to aluminum or beryl- lium).

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION							IBFS/IHS
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
45	Radiation, ionizing.	All	Radioactive decay of isotope.	Excessive ex- posure of per- sonnel during handling, loading, test, transport, and other opera- tions involv- ing IHS.	II- IV	II	Handling equipment, and test and opera- tional procedures must minimize the exposure of techni- cians, test conductors, QA, and health physics personnel in order that whole body dose rate of 5 rem per year is not exceeded.
46		All	Breach of fuel sphere assembly	Plutonium fuel released to environment.	II IV	?	The preliminary system safety review will examine poten- tial accidents/mal- functions which may lead to release of fuel. Development and demonstration of a reliable emergency cooling system for the HSA is recognized as a top priority item.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION				IBFS/ENTIRE SYSTEM			
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
47	Penetration of component (s)	OPO	Micrometeoroid impact	Penetration of W/F containment resulting in loss of W/F.	II-IV	?	Radiator most vulnerable; other components will be partially or totally shielded by space radiator. Multi-foil insulation will also provide degree of protection to insulated components. Design per NASA specification.
48	Major fire and/or explosion	PAD-LIO	Launch vehicle malfunction	Obviously catastrophic to IBFS and space vehicle.	IV	?	Nuclear safety ramifications TBD by preliminary system safety review.
49	Nuclear attack	OPO	Detonation of offensive nuclear war-head in space.	Dependent upon yield, proximity and other factors. Loss in radiator emissivity coating is but one example of damage which	II-IV	?	Potential kill mechanisms must be evaluated.

PRELIMINARY HAZARD ANALYSIS

SYSTEM/SUBSYSTEM IDENTIFICATION				IBFS/ENTIRE SYSTEM			
NO.	HAZARD/UNDESIREDEVENT	PROG. PHASE	CAUSE	EFFECT	HAZARD CATEGORY		CORRECTIVE ACTION/ MINIMIZING PROVISIONS
49	continued...			would directly affect BIPS power output.			
50	Acceleration	L10	Launch vehicle acceleration (dynamic load- ing)	Fracture of ducts or bellows, welds and brazes. Fracture of structural members.	II- IV	I	Proper design Use GDS to evaluate design and measure loads.